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A numerical and experimental investigation for a triangular storage collector

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ABSTRACT

In this study, an experimental and numerical investigation was conducted for a new solar collector design suitable for domestic utilization. The study was carried out to evaluate the performance of triangular collectors that were fabricated by cutting a cubic tank at different cutting planes.

Experiments were done at different conditions including during summer and winter with and without the removal of hot water outlet. A systematic investigation on the hourly performance parameters of the system was conducted in all test conditions, which included mean storage temperature, velocity distribution, total stored energy and the best location for inlet and outlet water flows. The results revealed that the triangular collector day-long collection efficiency under no load condition was found to be 48.7% during winter with 40.5 °C maximum mean storage temperature and 65 °C maximum temperature for the hot water from the collector tip. During summer, the day-long collection efficiency was found to be 62.2% with 57 °C maximum mean storage temperature and 70 °C maximum temperature for the hot water from the collector tip. At continuous loading of the triangular collector, the collection efficiency was 55.7% during winter and 65.1% during summer. At continuous loading condition test, the maximum temperature difference between the collector outlet and inlet water was found to be 12 °C at 2 PM and 9 °C at the end of the winter day.

To verify the experimental test results, a numerical study was conducted using Fluent software. The numerical results showed a good agreement with the experimental data obtained from this study.

1. Introduction

The current cost for air or water circulated flat plate collector, a professionally installed system, is around £150 per square meter (Duffie and Beckman, 2013). This high initial cost represents the main obstacle behind the limitation of implementing solar space heating or cooling for domestic utilization (Islam et al., 2013). It is the intent of this study to develop a low cost, reliable, and efficient solar water heater system for domestic use (Ahmed and Mohammed, 2017). All classical solar water heater systems contain two main components: a storage tank and a collector. Joudi (1990) suggested a new low cost storage solar collector for domestic hot water supply. The collector was fabricated easily from the commonly available commercial materials using simple tools and procedures. The advantage of the suggested collector design is that it can be used for water storage to replace the ordinary cubical or cylindrical water tank commonly used in Iraqi houses.

Ecevrr and Apaydn (1989) developed a new design of storage collector. The bulk efficiency of this design about 60. Ahmed (2018) analyzed a compact integral solar water heater design analytically and experimentally. The water tank and collector were combined in a single unit in the suggested design and the water flow was permitted by the thermsyphonic force. Another study investigated numerically the performance of a right triangular cross-sectional area prism-shaped storage solar collector using ANSYS software (Joudi et al., 2004). On the other hand, Ahmed (2017) studied the storage solar collector performance with cylindrical shape experimentally and numerically in Kirkuk city.

The invention includes an engineering design fabricated by cutting a cubic tank at different orientations. In this design, the ideal angle of inclination is 10–15° more than the latitude angle to collect the solar energy in winter season (Ahmed and Hussein, 2018). The latitude angle for Basra is 31°, Baghdad is 33° and Mosul is 36°. Accordingly, for ease and unity, a 45° common angle of inclination would be suitable (Helal et al., 2011). The volume of the collector can be controlled using different dimensions for the base and height simultaneously. To increase the absorption of solar energy, the sunlit surface has been painted black (Kumar and Rosen, 2011). A glass sheet or any other transparent materials can be used to cover the tilted side that is facing the sun and all the other sides can be insulated using thermal insulation. The current study has been conducted to investigate experimentally and numerically the performance of a triangular storage collector as shown in

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Nomenclature

A	height of the collector [m]
A_f	irradiated face of collector [m^2]
c_w	specific heat of water [J/kg·K]
I_{beam}	beam irradiance [W/m^2]
I_{total}	total solar radiation on a tilted surface [W/m^2]
m	mass of water in the collector [kg]
$\dot{m}$	mass flow rate [kg/s]
M_i	mass of specified slice [kg]
q_u	useful heat [W/m^2]
t	time [s]
T_{av}	average water temperature inside collector [°C]
T_{mf}	average temperature of tank at end period (without load) [°C]
T_{ms}	average temperature of tank at beginning of period (without load) [°C]
$\bar{T}_{outL}$	outlet temperature of load water from tank [°C]
$\bar{T}_{inL}$	inlet temperature of load water from tank [°C]
u	velocity component in x-direction [m/s]
v	velocity component in y-direction [m/s]
w	velocity component in z-direction [m/s]
η	instantaneous collector efficiency [–]
η_b	overall collector efficiency [–]

Fig. 1.

2. Description of the experimental apparatus

The experimental apparatus consists of a triangular storage collector, which has a triangular irradiated face area and a triangular right angle pyramid for storage as shown in Fig. 2. The back height is 500 mm, giving a volume of 41.7 L and a sunlit area of 0.35 m^2. Visualization of the convection flow currents inside the triangular collector was accomplished by injecting a small amount of red dye with a syringe into the body of water at two positions: at the tip of the collector (x = 50 mm, y = 400 mm and z = 5 mm) and at the base of the collector (x = 50 mm, y = 50 mm and z = 5 mm), as shown in Fig. 3. Observation of the subsequent dye motion was made through one of the side walls of the enclosure, which was fabricated from clear 3 mm Plexiglas. The interior of the collector, at the opposite side, was enhanced with a white background to facilitate visual observation as shown in Fig. 3. To enhance the absorption of sun radiation, matte black paint was used to paint the tilted sunlit surface. A cold water inlet pipe was connected at the bottom of the tank and a hot water outlet pipe was taken from the top of the tank.

An ordinary 4 mm thick window glass was used as the top transparent cover for the tilted surface that was facing the sun. The distance between the absorber plate and the bottom surface of the glass was kept at 45 mm (within the recommended value for solar collectors) (Buchberg et al., 1976). The glass cover edges were sealed with silicon tape to prevent hot air leakage from the gap between the glass cover and the absorbing surface.

The triangular storage collector was insulated with Styrofoam of 50 mm thickness at all sides. The storage collector and insulation were embraced by a wooden frame 300 mm above the ground. The irradiated face of all designs was inclined at 45° above the horizontal and facing south. Ten thermistors were fixed inside the collector storage that was incorporated into five vertical probes. Three probes were placed vertically along the section of symmetry of the storage collector as shown in Fig. 4 section A-A. Probe A holds one thermistor, Probe B holds two thermistors and Probe C holds three thermistors. Probes D and E were fixed away from the tank centerline at a distance of 250 mm as shown in Fig. 3 section B-B. Probe D holds one thermistor and Probe E holds two thermistors. The last thermistor (no. 1) was placed at one of the lower front corners of the storage at a distance of 500 mm from the centerline. The storage water inlet and outlet temperatures were measured using two separate thermistors. Furthermore, to measure the absorber plate temperature and glass cover temperature, two additional thermistors were used. Volumetric flow rate of the water supply through the test rigs was measured by a floating type rotameter. A computer program was prepared for the evaluation of hourly incident solar radiation on a tilted surface with a tilt angle of 45° for any day in the year. The ASHRAE clear day model was used (Duffie and Beckman, 2013). The stored energy of a collector for no load condition can be calculated as follows (Ahmed and Bawa, 2018):

$$q_u = m * c_w * (T_{mf} - T_{ms})/3600 \quad (1)$$

A few experiments were conducted by imposing a load on the system. In this case, the average temperature of the water withdrawn from the tank and the mains water temperature entering the tank were recorded in addition to other measurements. The heat collected by the system under load condition was estimated using the following equation (Fraisse et al., 2014):

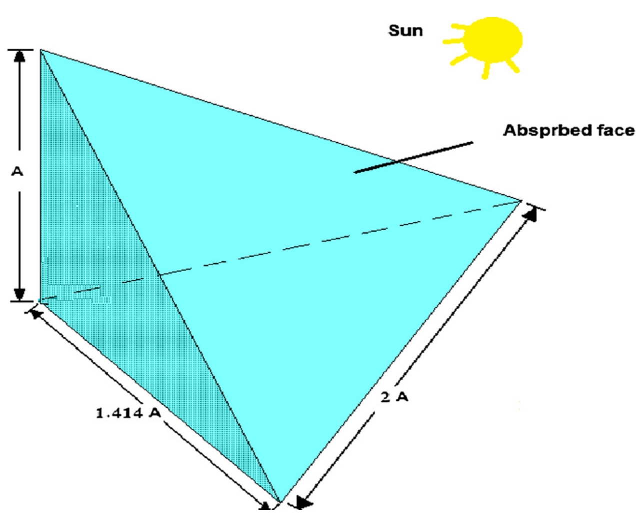

Fig. 1. Schematic diagram of a triangular storage collector.

Fig. 2. Triangular storage collector.